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Director, Central Irrigation on Hydrodynamic
Research Station, Poona.

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Government of Bombay
Public Works Department

Technical Paper No. 59

Silt Control At Heads of Canals and Distributaries

BY
C. C. INGLIS, C.I.E., B.A., B.A.I., M.INST.C.E.
and
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Assistant Engineer

FIRST EDITION

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SILT CONTROL AT HEADS OF CANALS AND DISTRIBUTARIES

BY

C. C. INGLIS, C.I.E., B.A., B.A.I., M.INST.C.E.,

and

Rao Sahib D. V. JOGLEKAR, B.E.,
Assistant Engineer.

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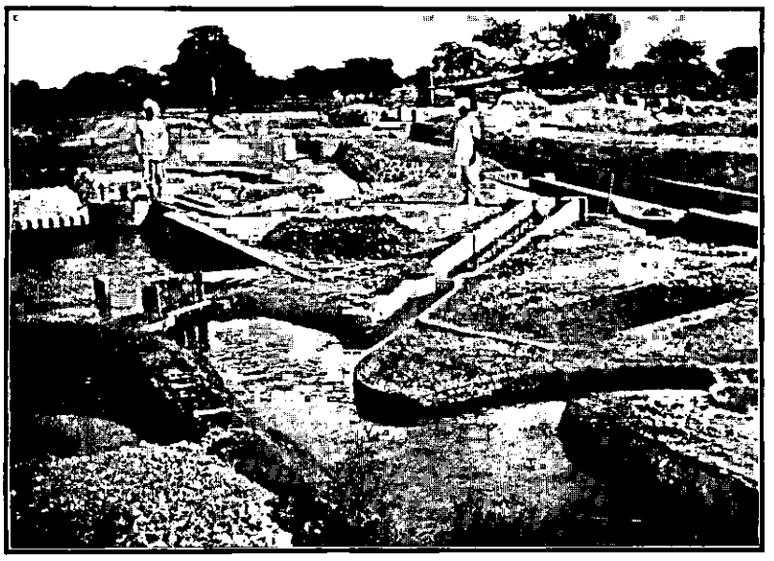
Distributary 5 Model of the Eastern Nara River at Makhi.

Makhi Regulator→

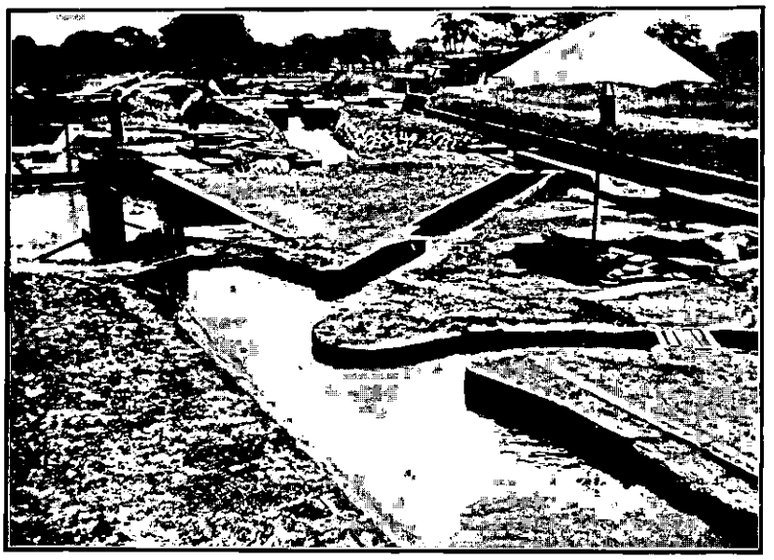


←Khipro Canal

←Mithrao Canal

838—Experiment No. 2.—*(Looking downstream). A spur projecting to midstream was built at the downstream end of the Mithrao to create curved flow to exclude bed silt.*

Makhi Regulator→

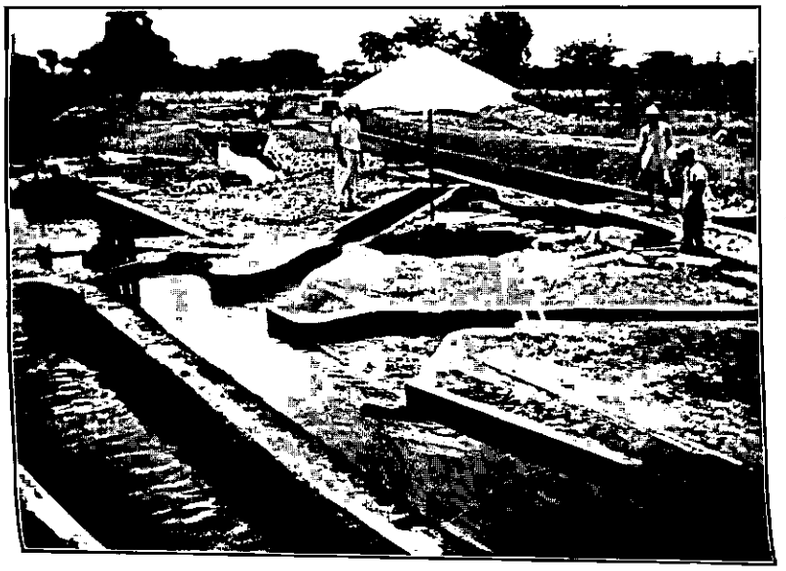


←Khipro Canal

←Mithrao Canal

855—Experiment No. 3.—*1 in 5 convergence upstream and a spur projecting to midstream downstream of the Mithrao. (Looking downstream).*

Makhi Regulator→



←Khipro Canal

←Mithrao Canal

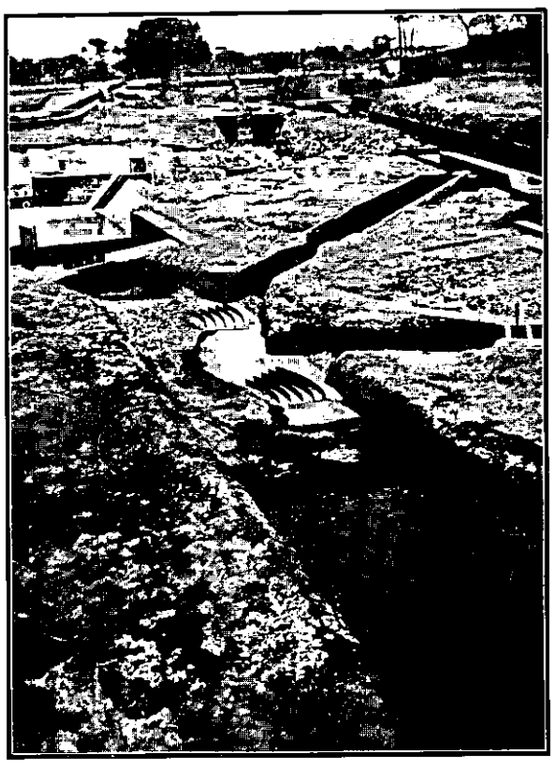
} Long raised sill with 1 in 5 convergence upstream.

865—Experiment No. 4.—*1 in 5 convergence upstream of the Mithrao and a long raised sill in front of the Mithrao and Khipro Canals. (Looking downstream).*

Model of the Eastern Nara at Makhi.

Makhi Regulator→

King's vanes→



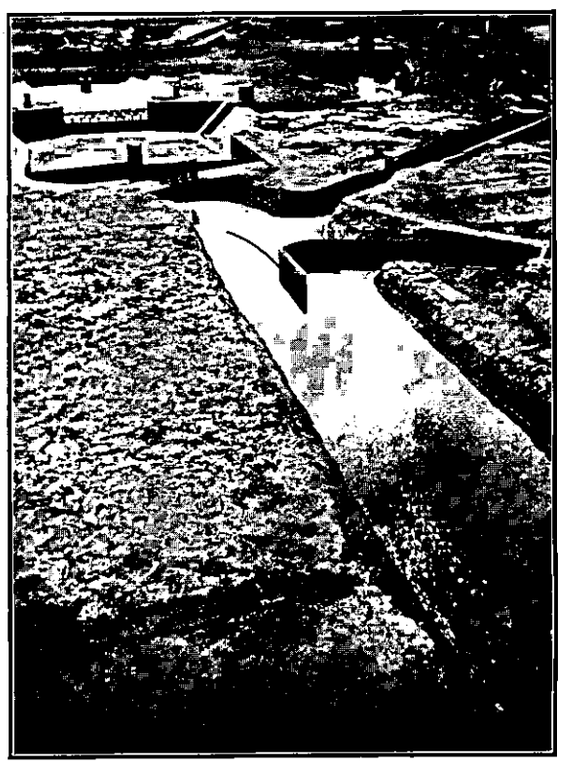
←Khipro Canal

←Mithrao Canal

←Nara River

890—Experiment No. 7(a).—*King's vanes opposite Mithrao and Khipro Canals. (Looking downstream).*

Divide wall with a large→ radius single vane d/s



←Khipro Canal Head

←Mithrao Canal

←Nara River

888—Experiment No. 8(a).—*Divide wall opposite Mithrao and a large radius single vane in continuation of the divide wall at the downstream end to exclude bed silt from Khipro Canal. (Looking downstream).*

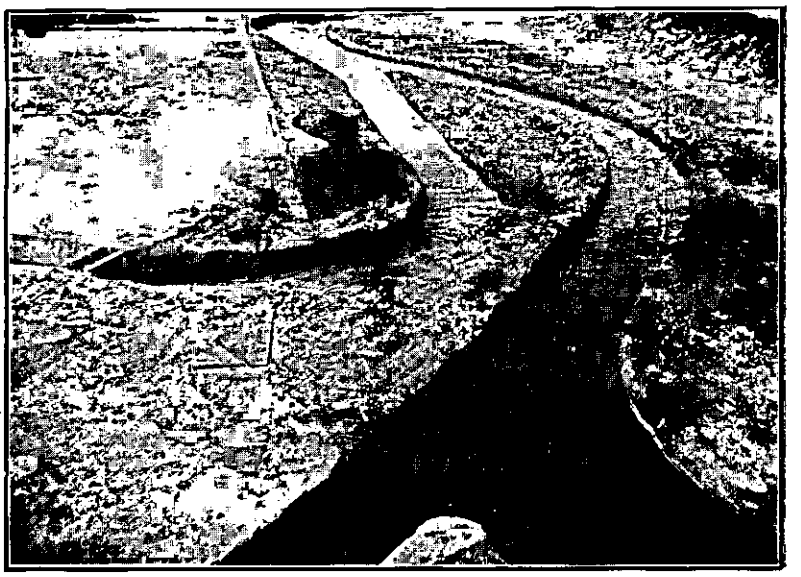
Distributary 5 Model of the Eastern Nara at Makhi.

←Makhi Regulator
←Khipro Canal
←Mithrao Canal

883—Experiment No. 10.—*With part of the old River channel opened to carry water to the Khipro Canal and the Makhi Regulator and the existing straight channel reduced in width to serve as an approach channel to the Mithrao Canal. (Looking downstream).*

Q of Nara above Makhi Regulator = 2·8 *cusecs* (= 7,120 *cusecs*).
Q of Mithrao = 0·84 *cusecs* (= 2,200 *cusecs*).
Q of Khipro = 0·56 *cusecs* (= 1,420 *cusecs*).

Mithrao Canal Head→



↑ Khipro Canal Head ↑ Makhi Regulator

882—*Looking upstream.*

1409.—*Showing the Eastern Nara on the left and the approach channel to the Mithrao on the right, shortly after construction. (Looking downstream).*

SILT CONTROL AT HEADS OF CANALS AND DISTRIBUTARIES.

(Experiments carried out in 1932-34.)

1. Introduction.

An earlier Paper of this series—Technical Paper 52 " Factors affecting exclusion of bed silt from Canals " may be read—with advantage—as an introduction.

In this Paper the control of silt entering the Mithrao Canal is the particular question dealt with; but the results are of wide application.

The Mithrao Canal derives its supply from the Eastern Nara above the Makhi Regulator; and the Eastern Nara—which also supplies water to the Jamrao Canal, some miles upstream and the Hiral and other Canals downstream was previously a river which drew its supplies from the River Indus above Sukkur; but it is now fed from the Eastern Nara Canal, the most upstream of the 4 Canals taking off from the left bank of the River Indus at the Sukkur Barrage.

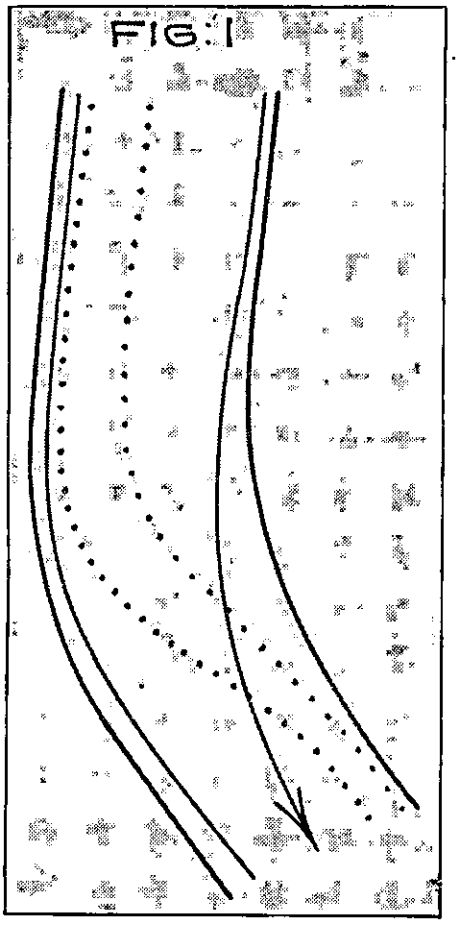
Coarser silt than previously drawn began to enter the Mithrao in 1932; and, as the slope required to pass silt varies as (diameter)$^{5/6}$[1] the previous drop into the Canal of 2 feet 6 inches at Full Supply discharge gradually disappeared *i.e.*, command was lost. Now, this is a very serious matter; because the slope required (for the same silt) increases inversely as the $\frac{1}{6}$th power of the discharge : $S \times \frac{f^{5/3}}{Q^{1/6}}$ So, once command is lost, deterioration is rapid.

Several different methods were tested :—

(*i*) Spur downstream of Mithrao Canal Head.
(*ii*) Same, with 1 in 5 converging approach upstream of Mithrao.
(*iii*) 1 in 5 converging approach combined with high sills.
(*iv*) Same, but allowing for scour of opposite bank.
(*v*) Single, large-radius, vane upstream of Mithrao Canal.
(*vi*) King's vanes.
(*vii*) Divide wall.
(*viii*) Old (River) conditions before the Nara was canalised.
(*ix*) Approach channel from concave bend upstream.

In the first 7 methods, curvature of flow was induced in order to sweep away bed silt from the face of the Canal Regulator; in (*viii*) some natural curvature existed, and in (*ix*) the old river bed was partly reopened to carry water to the Makhi Regulator and Khipro Canal—; the existing straight channel, after reduction in width, being used as an approach channel to the Mithrao Canal. This lay-out was such that the approach channel took off where the beneficial effect of curvature was a maximum.

The simplest way to explain the effect of curvature is to cite the case of a channel in which a straight reach is followed by a curve—see Fig. 1 :



Full lines show lines of flow of surface water———

Dotted lines show lines of flow of bed water.....

[1] Gerald Lacey Paper No. 4736, Instt. of Civil Engineers on " Stable channels in alluvium (1930)" and No. 4893 on " Uniform flow in alluvial rivers and canals (1934)."

The top water, flowing with a relatively high velocity, tends to flow straight on ; while the bed water—which contains the coarse silt—has a relatively low velocity, and so is easily deflected towards the convex bank, due to the " total energy of flow " being greater at the concave bank than at the inside of the curve.

All the methods tried reduced the quantity of silt drawn, and nearly all had some special advantage.

The last method was adopted, not merely because it was the most effective in reducing silt entering the Mithrao ; but also because remodelling could be carried out without interfering appreciably with canal administration.

As a result of remodelling, " command " was at once restored.

2. Experiments.

Experiment No. 1.—Conditions in 1932.

The Full Supply Discharge of the Eastern Nara upstream of the Mithrao Canal was 7,120 cusecs, consisting of—

Mithrao Canal	2,200 cusecs.
Khipro Canal	1,420 cusecs
	3,620 cusecs or 51 per cent. of parent channel discharge.

The model scale ratios—based on Lacey's formulae—were :—

Horizontal scale	1/60
Vertical scale	1/14·2
Time scale	1/17·4

Figure 2 shows the conditions when ' control ' was lost. It also shows silt contours, after silt had been injected for 3 hours, and lines of flow of bed water indicated by seeds.

The ratios of silt recovered per cusec in the Mithrao and Khipro Canals compared to that recovered from the Nara were 2·15 and 0·81 respectively, indicating that a large proportion of the bed silt was being carried into the Mithrao Canal.

Experiment No. 2.—*See* photo 838 and Fig. 3.

In order to create curved flow, a spur was built out downstream of the Mithrao Head Regulator, extending to midstream. This reduced the coarse silt entering the Mithrao to about half and the ratios to 1·04 and 0·63 respectively ; but created violent eddy action.

Experiment No. 3.—*See* photo 855 and Fig. 4.

In this experiment a 1 in 5 convergence, in which the side was warped from the natural side slope of the Nara to vertical, was added upstream of the Mithrao offtake. This, further reduced the amount of bed silt entering the Mithrao and Khipro Canals, but did not reduce the downstream turbulence.

Experiment No. 4.—*See* photo 865 and Figs. 5 and 6.

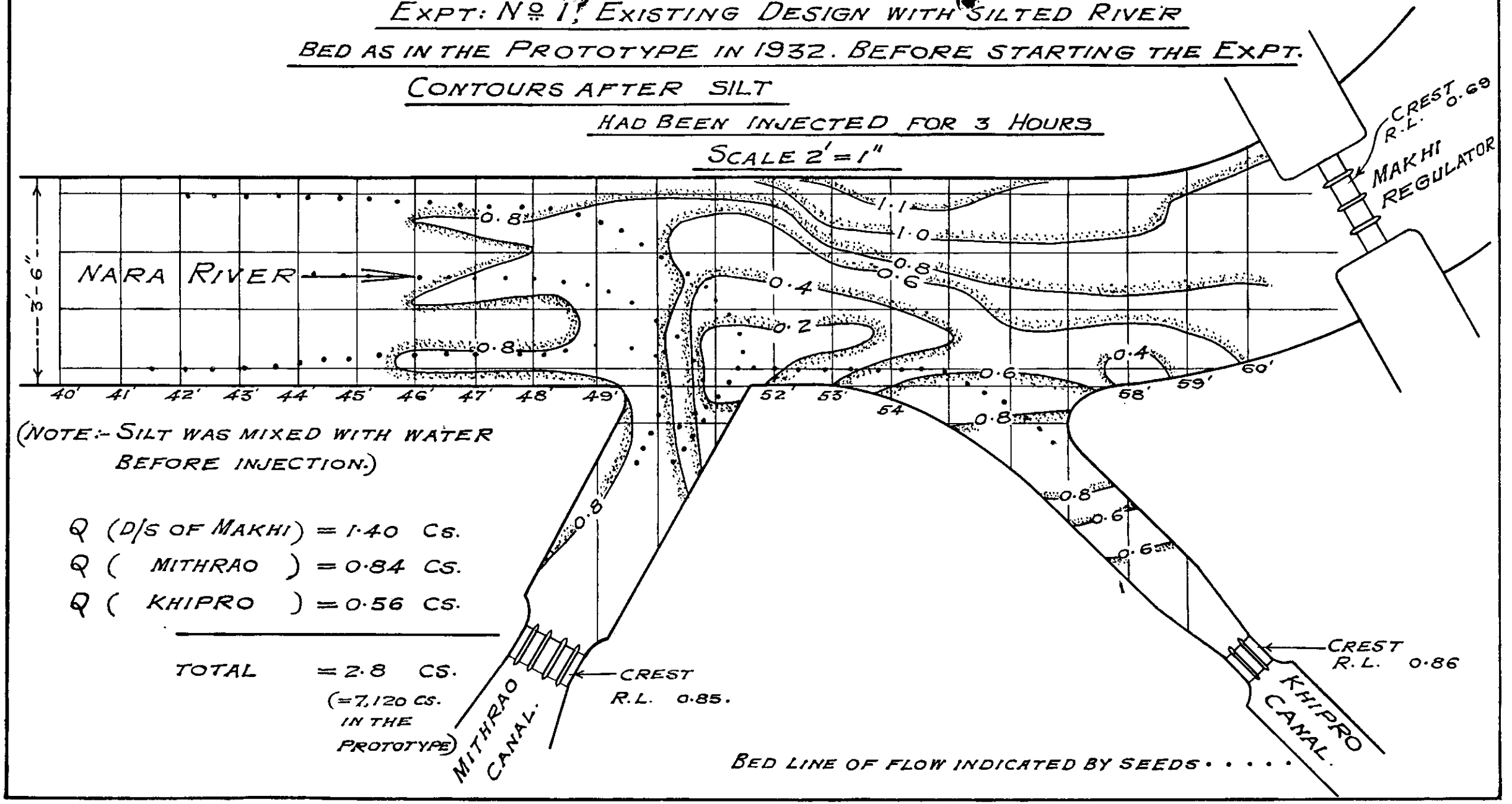
In this design, curvature of flow was created by a 1 in 5 warped convergence upstream—as in Experiment 3—combined with long, high sills. This design gave highly successful results so long as the opposite bank was not allowed to scour, the ratios of silt in Mithrao and Khipro to the silt per cusec in the Nara being reduced to ·26 and ·25 respectively. If, however, the left bank was not strongly protected, so that scour took place—see Fig. 6— the Khipro Canal would receive a considerable silt charge, the ratio $\frac{\text{Khipro}}{\text{Nara}}$ rising from ·25 to ·93, and conditions would tend to get worse.

FIG: 2 MODEL OF THE EASTERN NARA [illegible]

EXPT: No. 1. EXISTING DESIGN WITH SILTED RIVER BED AS IN THE PROTOTYPE IN 1932. BEFORE STARTING THE EXPT.

CONTOURS AFTER SILT HAD BEEN INJECTED FOR 3 HOURS

SCALE 2' = 1"



(NOTE:- SILT WAS MIXED WITH WATER BEFORE INJECTION.)

Q (D/S OF MAKHI) = 1.40 CS.
Q (MITHRAO) = 0.84 CS.
Q (KHIPRO) = 0.56 CS.

TOTAL = 2.8 CS.
(=7,120 CS. IN THE PROTOTYPE)

BED LINE OF FLOW INDICATED BY SEEDS . . . . .

C.P.W.D. POONA, 1938.

Fig. 3, Part II

EASTERN NARA WITH HEAD REGULATORS OF MITHRAO AND KHIPRO CANALS AND MAKHI REGULATOR

SCALE:- 2'=1"

Q OF NARA RIVER U/S OF REGULATOR = 2·8 Cs (=7120 Cs)
Q OF MITHRAO CANAL = 0·84 Cs (=2200 Cs)
Q OF KHIPRO " = 0·56 Cs (=1420 Cs)

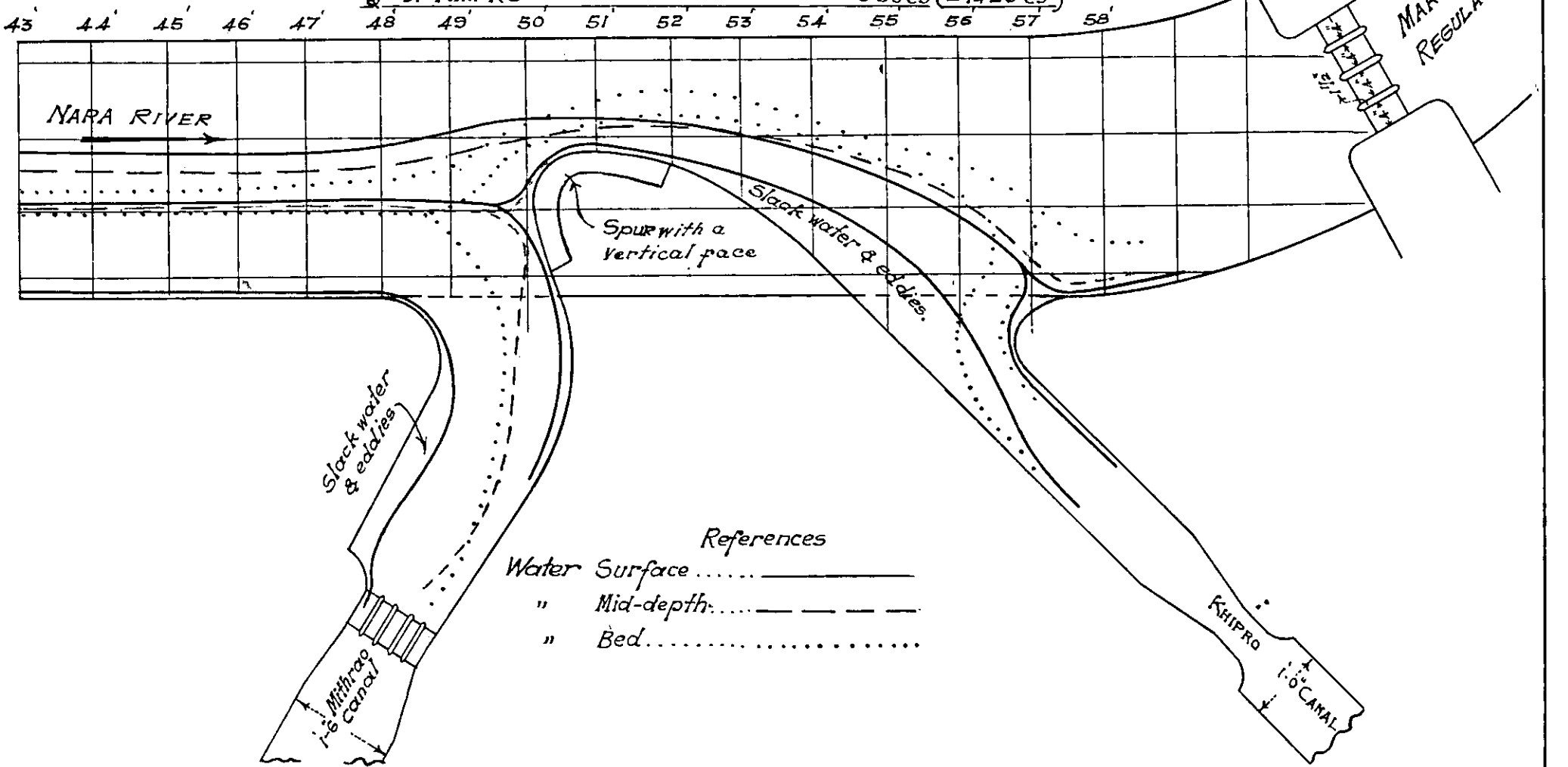


Fig. 4, Exp. No. of Sheet

OF MITHRAO AND KHIPRO CANALS AND MAKHI REGULATOR

1 in 5 Convergence u/s and Projecting spur d/s of Mithrao.

Scale :- 2' = 1 inch

Q of Nara River u/s of Regulator = 2·8 cs. (= 7120 cs.)

Q of Mithrao Canal = 0·84 cs. (= 2200 cs.)

Q of Khipro " = 0·56 cs. (= 1420 cs.)

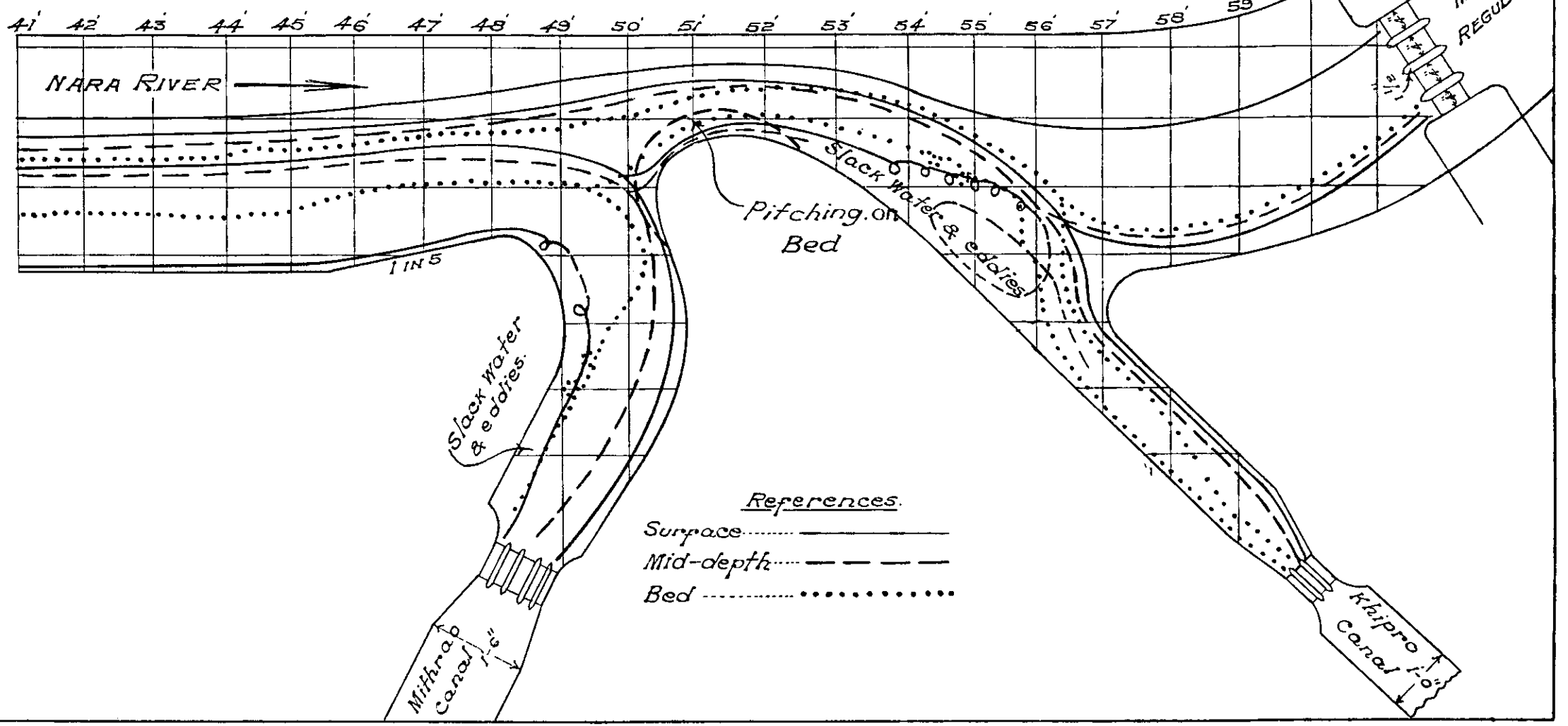


FIG: 5, EXPT: No. 4, OF EASTERN NARA WITH HEAD REGULATORS OF MITHRAO AND KHIPRO CANALS AND MAKHI REGULATOR

No. 472
FIG: 5.

1 in 5 Convergence u/s of Mithrao and long high sill infront of Regulators.

SCALE:- 2' = 1 inch

Q of Nara River u/s of Regulator = 2·8 Cs. (=7120 Cs.)
Q of Mithrao Canal = 0·84 Cs. (=2200 Cs.)
Q of Khipro " = 0·56 Cs. (=1420 Cs.)

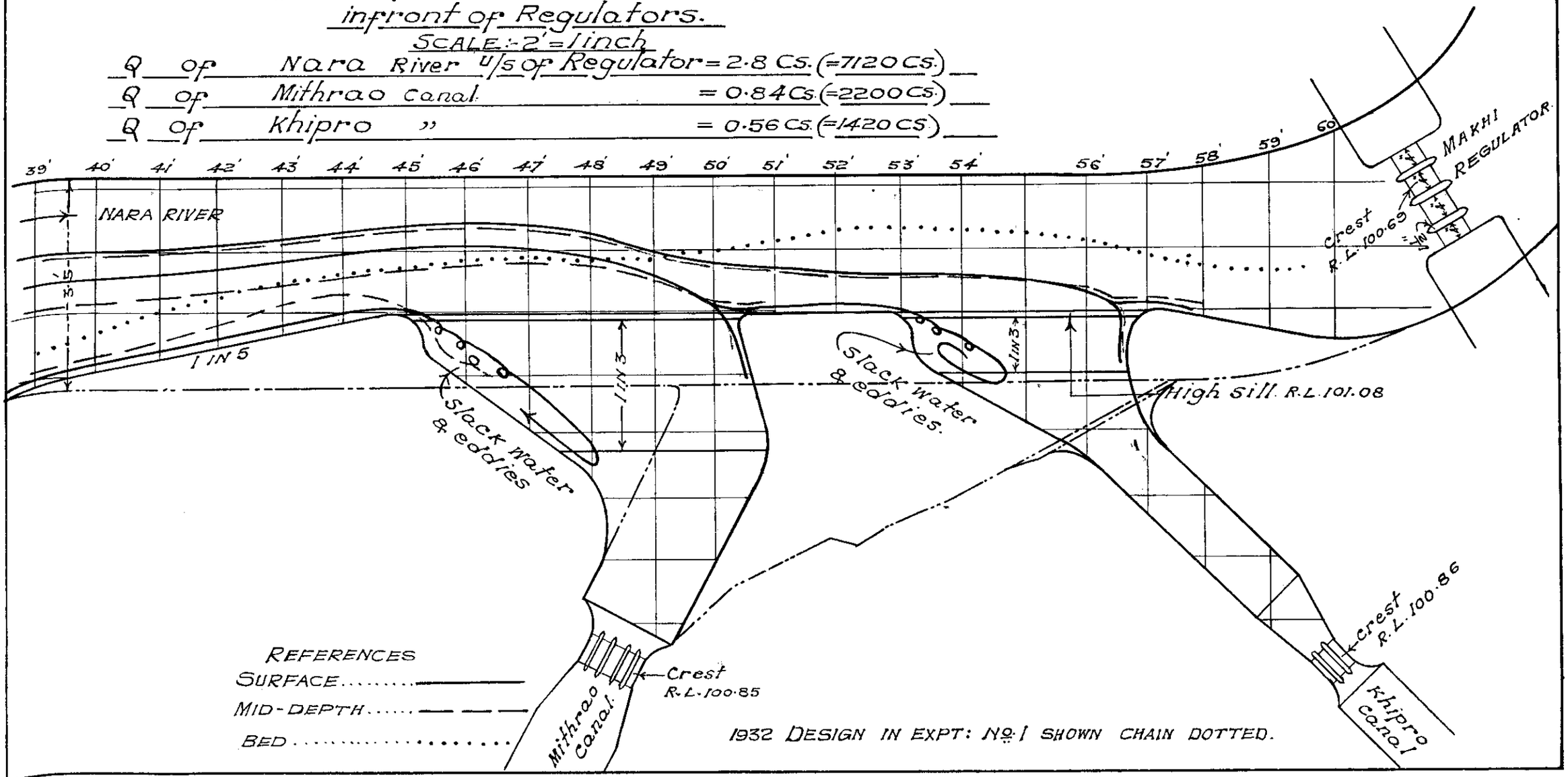


FIG: 6, EXPT: Nº 4A, WITH THE MODEL OF THE EASTERN NARA AT MAKHI.

WITH SILTED RIVER BED (1932 CONDITIONS.)

AND ALLOWING FOR SCOUR ALONG THE LEFT BANK DUE TO 1 IN 5 CONVERGENCE.

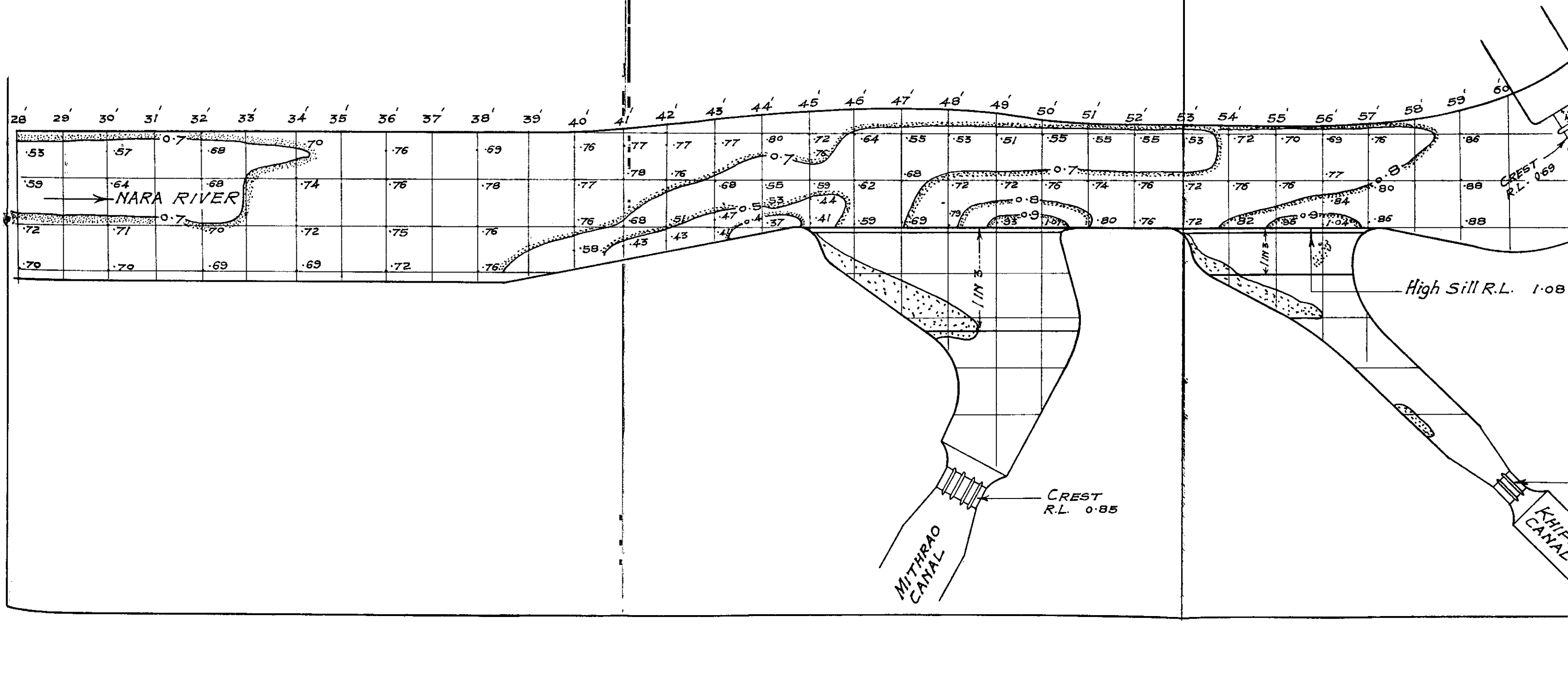
SCALE 2 = 1 INCH.

Q (d/s of Makhi.) = 1·4 Cs, (3,560 Cs.)

Q (Mithrao.) = 0·84 Cs, (2,140 Cs.)

Q (Khipro.) = 0·56 Cs, (1,420 Cs.)

Total = 2·8 Cs, (=7120 Cs.)



This design—with adequate protection of the left bank—was actually recommended, but was not adopted: partly because the cost would have been high, but chiefly because it would have necessitated closing the Canals for a considerable time, which would have led to damage to crops.

Experiment No. 5.—See Fig. 7.

In this experiment, a single, large-radius vane was constructed upstream of the Mithrao Canal. This vane had a vertical face of height equal to $\frac{1}{3}$rd the depth of water, and was protected by downstream pitching—sloping at 1 in 3—to prevent scour and insure sweet flow. The vane was tried at several positions; and the best result was obtained when it started at C. S. 47. The ratios of silt in water entering the Mithrao and Khipro (per cusec) to that passing down the Nara were 1·02 and 1·01 respectively—in other words, this device gave proportional distribution and was not sufficiently "silt-reducing" for this particular case.

Experiment No. 6.—See Fig. 8.

Six King's vanes were constructed opposite the Mithrao Canal Head, of height equal to $\frac{1}{3}$rd the depth of water, spaced $1\frac{1}{2}$ times their height apart. With these, the ratios of silt recovered from the Mithrao and Khipro to that recovered from the Nara per cusec were ·67 and 1·33 respectively. The silt draw was thus excessive in the case of the Khipro Canal.

Experiment No. 7 (a) to (e).—See Photo 890 and Fig. 9.

In this experiment, additional King's vanes were constructed in front of the Khipro Canal Head. A series of 5 experiments was run with discharges in accordance with discharges of 1932.

Experiment No. 8 (a) to (e).—See Photo 888 and Fig. 10.

In this series, a "Divide wall" was constructed opposite the Mithrao—to create "Still pond" conditions for the Mithrao [2]—and a large-radius vane was built in continuation of the "Divide wall" to reduce the amount of bed silt entering the Khipro Canal. In this case, as in the previous experiment, 5 experiments were done with discharges of 1932. The results of the two experiments will be considered together:—

TABLE 1.

Nara discharge above canals.	Ratio of silt charges. Mithrao Canal. E. Nara d/s in		Ratio of silt charges. Khipro Canal. E. Nara d/s. in		Remarks.
	Experiment 7 King's Vanes.	Experiment 8 Divide wall.	Experiment 7 King's Vanes.	Experiment 8 Divide wall.	
7,120 cusecs	0·42	0·52	0·83	0·90	Discharges in experiments (*a*) & (*e*)—Mithrao Canal 2,200 cusecs (31 per cent.). Khipro Canal 1,420 cusecs (20 per cent.). Nara downstream 3,500 cusecs. (49 per cent.).
5,432 „	0·63	0·69	0·88	1·16	
2,682 „	1·08	0·32	0·65	0·34	
5,432 „	0·45	0·39	0·70	0·72	Discharges in experiments (*b*) & (*d*)—Mithrao Canal 1,928 cusecs (35 per cent.). Khipro Canal 1,248 cusecs (23 per cent.). Nara downstream 2,256 cusecs. (42 per cent.).
7,120 „	0·29	0·20	0·60	0·43	In (*c*), Mithrao drew 1,280 cusecs (47½ per cent.) and Khipro 1,196 cusecs, (44½ per cent.).

[2] Technical Paper 45 "Silt exclusion from Canals." "Still Pond" versus "Open Flow" by C. C. Inglis.

King's vanes gave better results at first; but subsequently the Divide wall gave better exclusion. King's vanes were less reliable; because their efficiency depended to a marked degree on their being in line with the oncoming current: Consequently, should any change occur in the regime of the parent channel, so that the line of flow became modified; or should any silting occur in their vicinity, they would cease to be effective, and in some conditions it was found that they tended to throw bed silt into suspension. While, therefore, they are effective in small channels under complete control, they are not suitable where changes of regime are liable to occur.

Though the "Divide wall" design was satisfactory in performance, it would have necessitated closing down the Nara during construction, and hence was not suitable.

Experiment No. 9.—See Figs. 11 and 12.

In this experiment the old River channel was reopened.

It was found that the $\frac{\text{Mithrao}}{\text{Nara}}$ and $\frac{\text{Khipro}}{\text{Nara}}$ ratios were 1·04 and ·72 respectively. Several modifications were tried—see Fig. 12—but no appreciable improvement resulted; and hence no solution was possible on these lines.

Experiment No. 10.—See photos 882, 883 and Fig. 13.

In this design, part of the old River channel was opened to carry water to the Khipro Canal and the Makhi Regulator, and the existing straight channel was reduced in width to serve as an approach channel to the Mithrao Canal.

This experiment was run for 4 periods of 3 hours each and gave ratios of silt in water entering the Mithrao and Khipro to that passing down the Nara per cusec as shown in the following table :—

TABLE 2.

Silt ratios during	Mithrao / E. Nara d/s.	Khipro / E. Nara d/s.
1st period of 3 hours	·09	1·11
2nd period ,, ,, ...	·05	·57
3rd ,, ,, ,, ...	·04	·53
4th ,, ,, ,, ...	·07	·44

Comparing the above with ratios for conditions in 1932 (=2·15 and ·81 respectively) it will be seen that the bed silt entering the Mithrao was markedly reduced. As a result of this, the silt passing down the Nara was correspondingly increased; so that though the Khipro ratio was improved from ·81 to ·44 the ratio of silt drawn by the Khipro to that of the parent channel upstream remained the same. This design was recommended and adopted.

Experiment No. 11.—See Fig. 14.

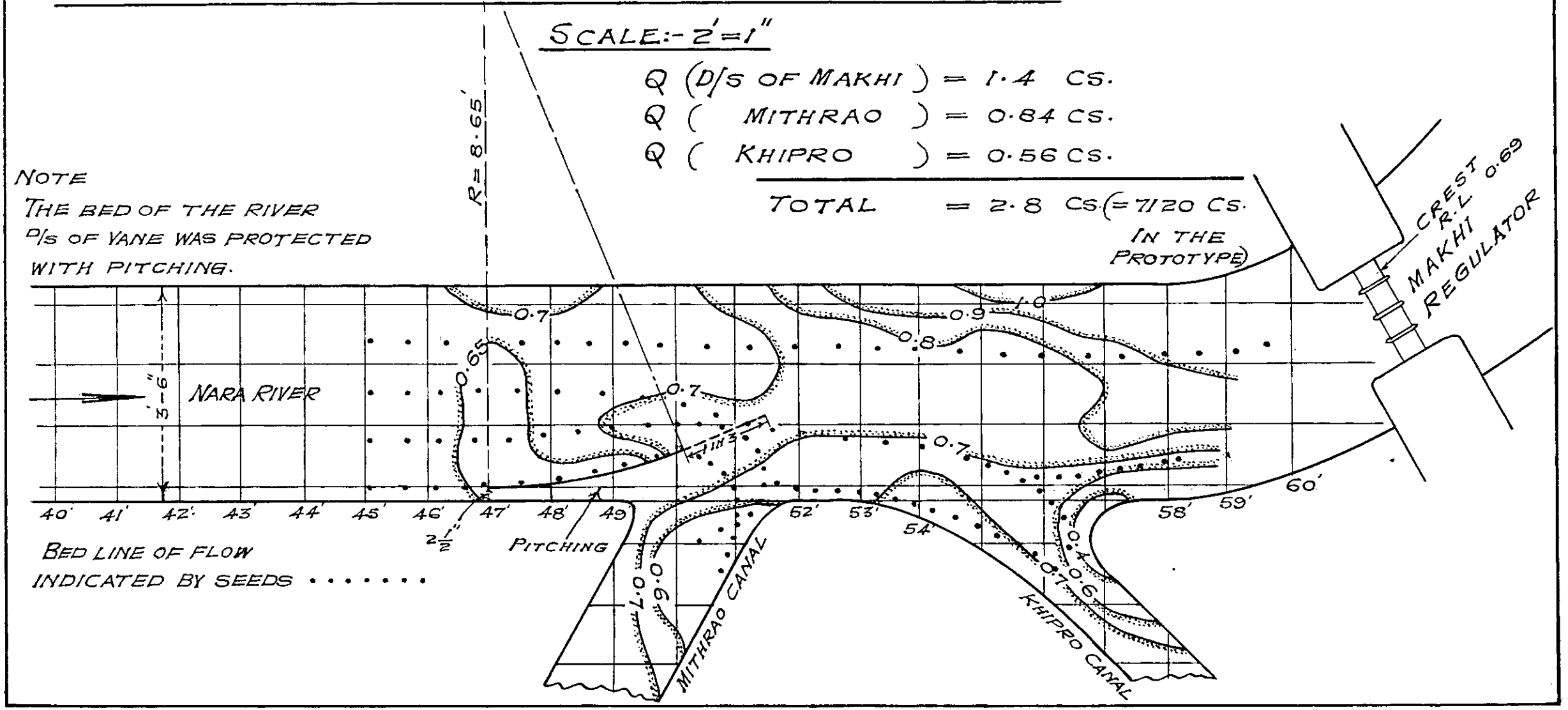
Although the quantity of silt drawn into the Khipro was still insufficient to be troublesome, it was desirable to show, in the model, how silt could, if necessary, be excluded from this Canal also.

In this experiment, the approach to the Khipro Canal was made to take off from the Mithrao approach channel instead of from the River. The width of the Mithrao approach channel was increased from the equivalent of 132 to 162 feet and that of the River was reduced from 132 to 90 feet—as shown in blue in Fig. 14, so as to maintain the ratio of discharge per foot run in the River and the approach channel the same as in experiment 10.

FIG. 7, MODEL ...

EXPT. No. 5 WITH A SINGLE VANE AND WITH SILTED RIVER BED. (1932 IN THE PROTOTYPE)

CONTOURS AFTER SILT HAD BEEN INJECTED FOR 3 HOURS


SCALE:- 2'=1"
Q (D/S OF MAKHI) = 1·4 CS.
Q (MITHRAO) = 0·84 CS.
Q (KHIPRO) = 0·56 CS.
TOTAL = 2·8 CS. (= 7120 CS. IN THE PROTOTYPE)
NOTE
THE BED OF THE RIVER D/S OF VANE WAS PROTECTED WITH PITCHING.
R = 8·65'
CREST R.L 0·69 MAKHI REGULATOR
NARA RIVER
3'-6"
2½"
PITCHING
MITHRAO CANAL
KHIPRO CANAL
BED LINE OF FLOW INDICATED BY SEEDS .....
0·7
0·65
0·8
0·9
1·0
0·6
0·4
40' 41' 42' 43' 44' 45' 46' 47' 48' 49' 52' 53' 54' 58' 59' 60'

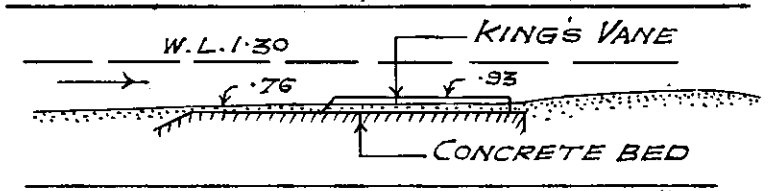
EXPT. No. 6 WITH KING'S VANES OPPOSITE MITHRAO

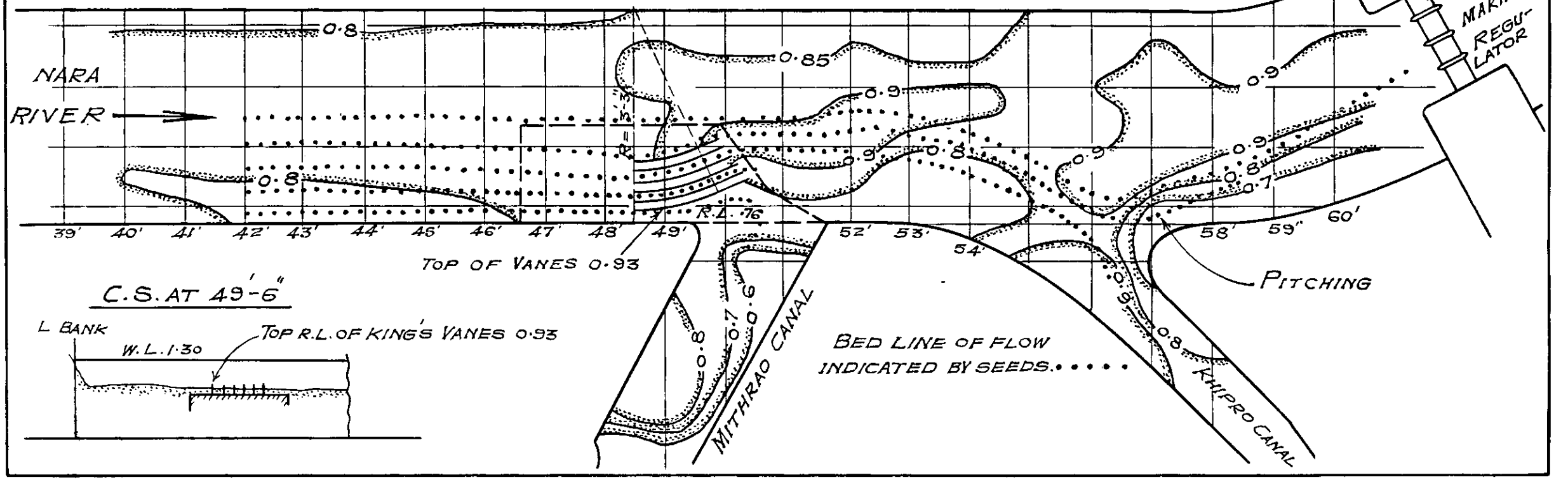
(SILTED RIVER BED AS IN THE PROTOTYPE IN 1932 BEFORE STARTING THE EXPT.)

SILT CONTOURS AFTER SILT HAD BEEN INJECTED FOR 3 HOURS.

SCALE:- 2' = 1"

L. SECTION ALONG U/S FACE OF 1ST: VANE





C.S. AT 49'-6"

FIG: 9, MODEL OF THE EASTERN NARA AT MAKHI REGULATOR.

EXPERIMENT No. 7 ——— FALLING GAUGE.

(i) SILT WAS LAID ACCORDING TO 1932 SOUNDINGS IN THE PROTOTYPE,-
BEFORE STARTING THE EXPERIMENT.

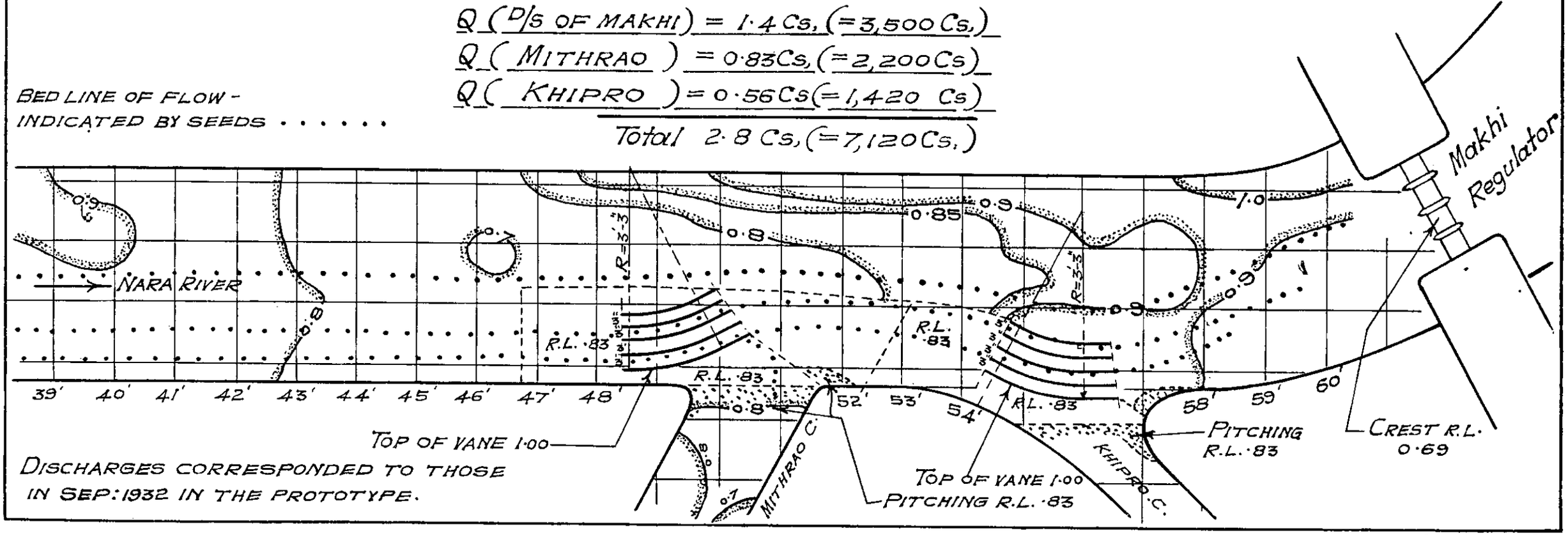
(ii) WITH KING'S VANES OPPOSITE MITHRAO AND KHIPRO.

CONTOURS AFTER 3 HOURS FLOW (DURING WHICH SILT WAS INJECTED.)

SCALE 2'=1 INCH

Q (D/S OF MAKHI) = 1·4 Cs, (=3,500 Cs,)
Q (MITHRAO) = 0·83Cs, (=2,200Cs)
Q (KHIPRO) = 0·56Cs (=1,420 Cs)
Total 2·8 Cs, (=7,120Cs,)

BED LINE OF FLOW - INDICATED BY SEEDS . . . . . .



DISCHARGES CORRESPONDED TO THOSE IN SEP: 1932 IN THE PROTOTYPE.

G. P. W. D. POONA. 1938.

FIG: 10. PLATE II No 517

MODEL OF THE EASTERN NARA AT MAKHI

EXPERIMENT No 8 (a)F – FALLING GAUGE.

(i) Silt was laid according to 1932 soundings in the prototype before starting the experiment.

(ii) With a short 'divide wall' opposite Mithrao and a single curved Vane (R=6'-8") d/s of the 'divide-wall' for Khipro. Contours after silt had been injected for 3 hours.

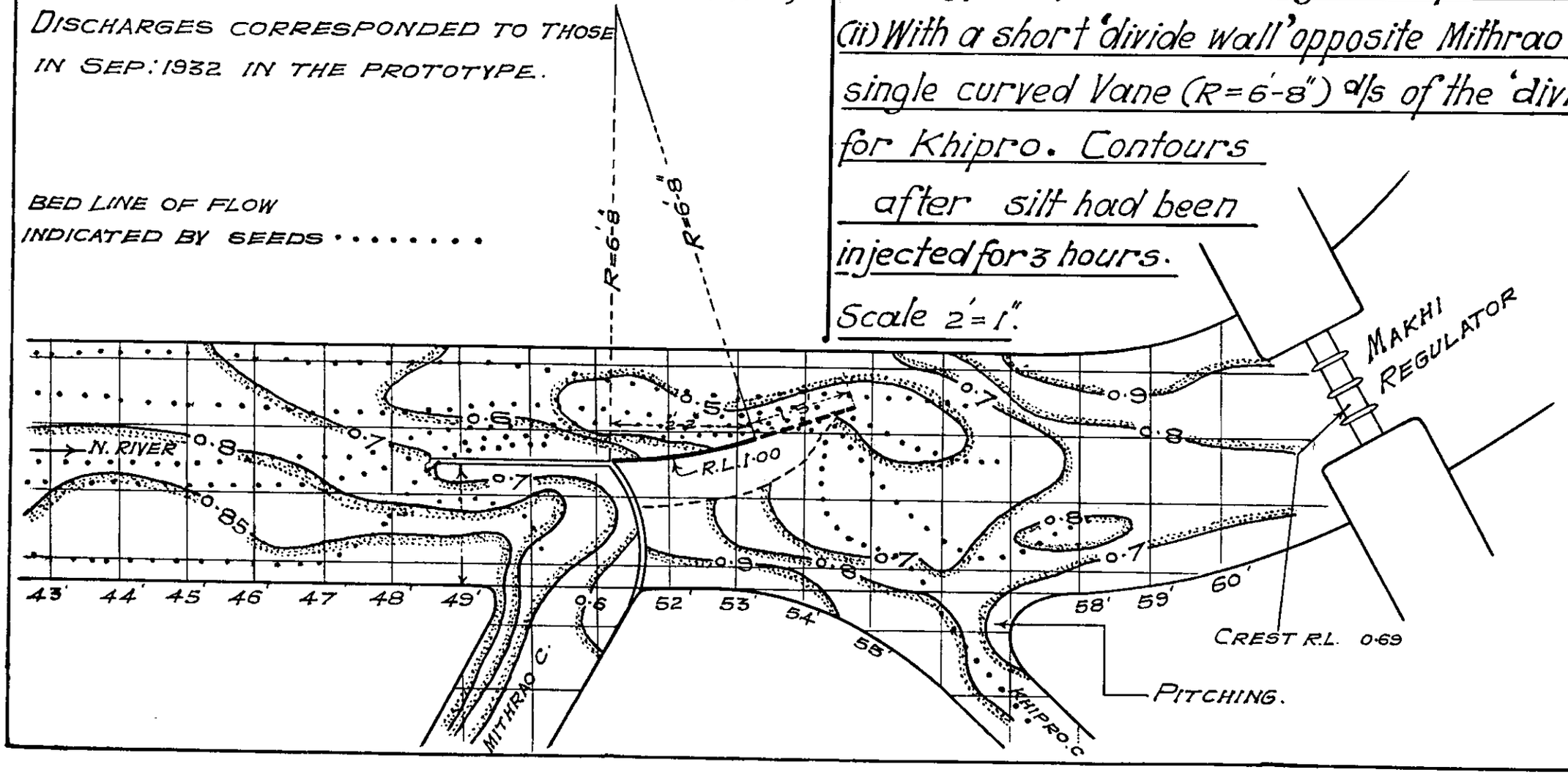
Scale 2'=1".

Q DOWNSTREAM OF MAKHI = 1·4 Cs: (=3,500 Cs:)
Q (MITHRAO) = 0·84 Cs: (=2,200 Cs:)
Q (KHIPRO) = 0·56 Cs: (=1,420 Cs)

2·8 Cs: (=7,120 Cs: IN THE PROTOTYPE.)

DISCHARGES CORRESPONDED TO THOSE IN SEP: 1932 IN THE PROTOTYPE.

BED LINE OF FLOW INDICATED BY SEEDS .....

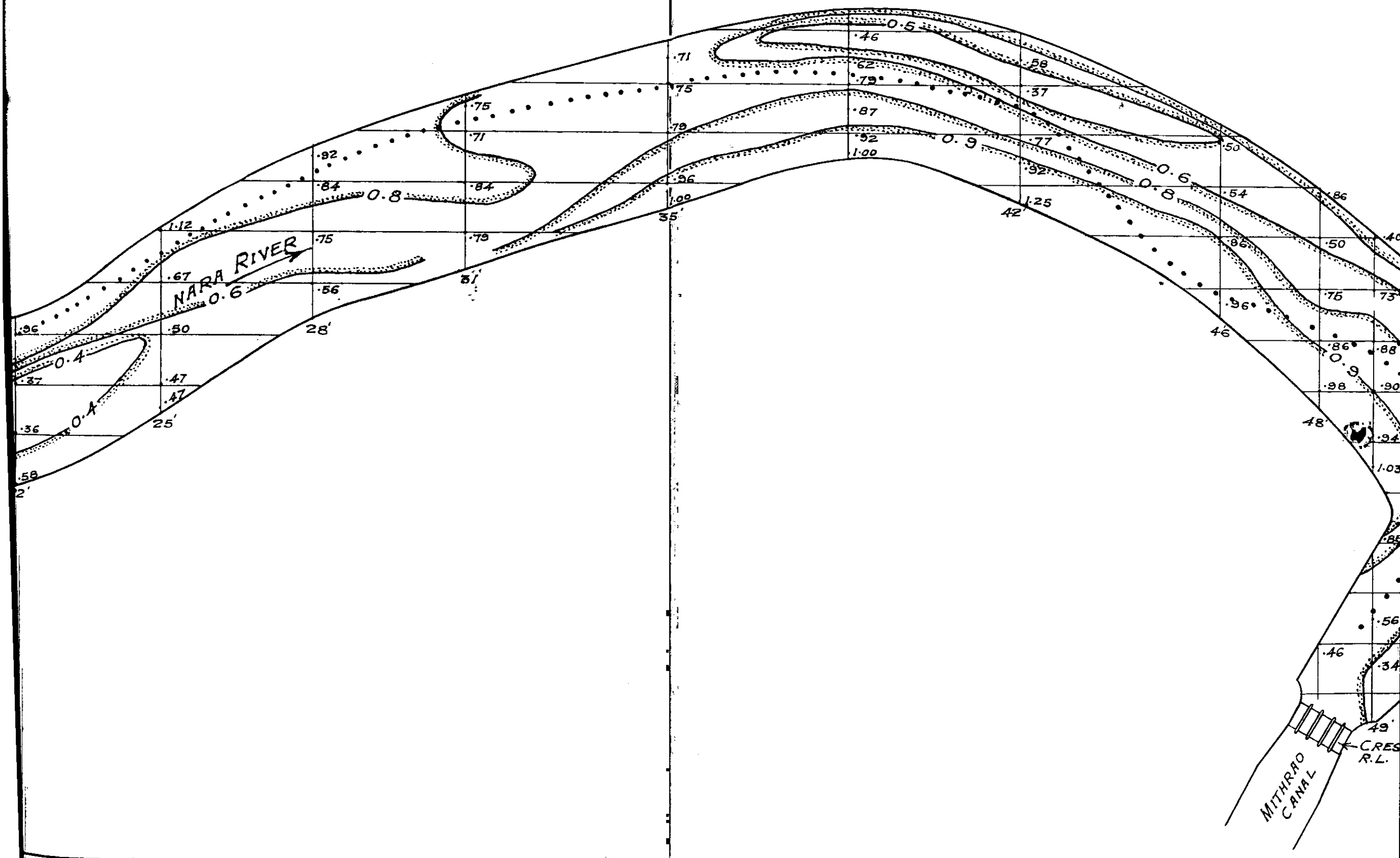


...EXPT. No. 3. WITH THE MODEL OF THE EASTERN NARA AT MAKHI

The old river was reopened & the remodelled river was closed in this

Contours after Silt had been Injected for 3 hours.

Q (d/s of Makhi Weir) = 1·4 Cs. (≡ 3,560 Cs.)
Q (Mithrao) = 0·84 Cs. (≡ 2,140 Cs.)
Q (Khipro) = 0·56 Cs. (≡ 1,420 Cs.)
Total = 2·8 Cs. (≡ 7,120 Cs.)



Poona, 1938.

No 502
FIG: II.

Expt.

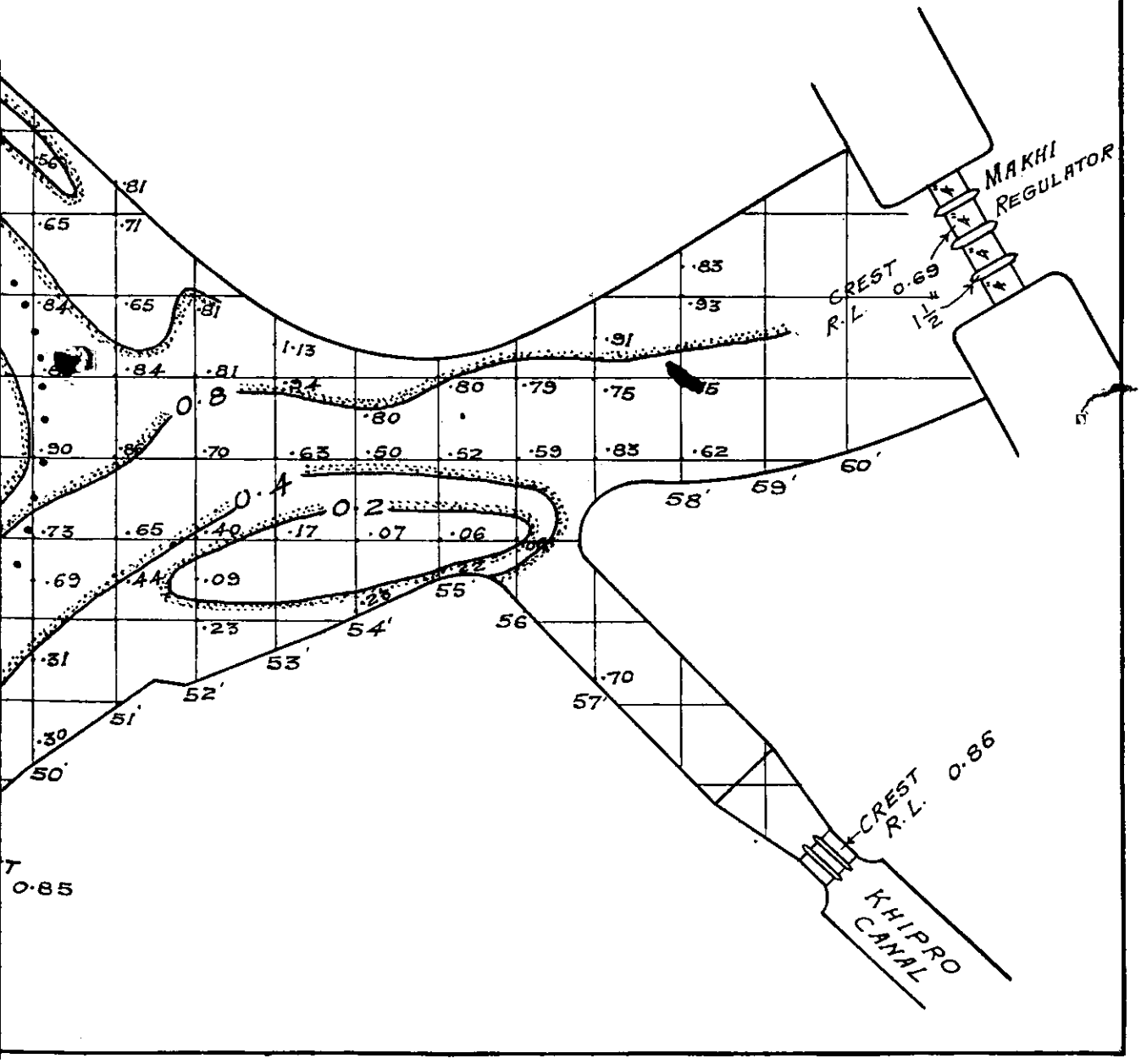


FIG: 10. PLATE II No 517

MODEL OF THE EASTERN NARA AT MAKHI

EXPERIMENT No 8 (a)$_F$ – FALLING GAUGE.

(i) Silt was laid according to 1932 soundings in the prototype before starting the experiment.

(ii) With a short 'divide wall' opposite Mithrao and a single curved Vane (R=6'-8") d/s of the 'divide-wall' for Khipro. Contours after silt had been injected for 3 hours.

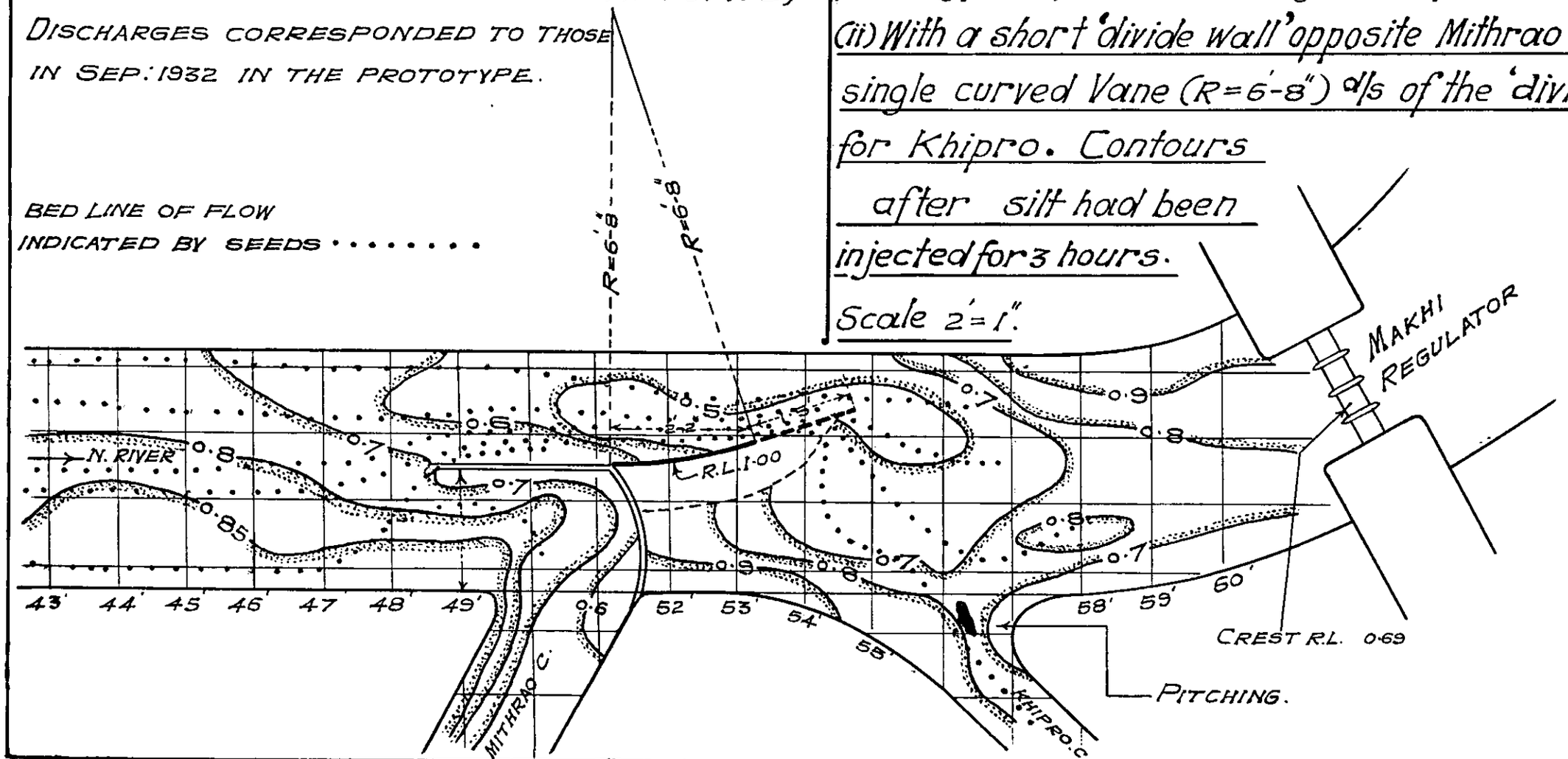
Scale 2'=1".

Q DOWNSTREAM OF MAKHI = 1·4 Cs: (=3,500 Cs:)
Q (MITHRAO) = 0·84 Cs: (=2,200 Cs:)
Q (KHIPRO) = 0·56 Cs: (=1,420 Cs)

2·8 Cs: (=7,120 Cs: IN THE PROTOTYPE.)

DISCHARGES CORRESPONDED TO THOSE IN SEP: 1932 IN THE PROTOTYPE.

BED LINE OF FLOW INDICATED BY SEEDS ·····



GIP.Z.O. POONA.1938.